INSTITUTE FOR SUSTAINABLE ENERGY, UNIVERSITY OF MALTA

SUSTAINABLE ENERGY 2013:
THE ISE ANNUAL CONFERENCE
Thursday 21st March 2013, Dolmen Hotel, Qawra, Malta

PERFORMANCE OF A SOLAR-ASSISTED THERMODYNAMIC HEAT PUMP FOR WATER HEATING

Charles Yousif[1], Irene Teresa Cubero[2] and Martin De Bono[3]
[1]Institute for Sustainable Energy, University of Malta, Malta
[2] Universidad de Valladolid, Valladolid, Spain
[3] CD Power Solutions Ltd, Ciancio House, Cannon Road, Qormi, QRM 9030, Malta
Corresponding Author E-mail: mdebono@powersolutions.com.mt
Tel: (+356) 21480500

ABSTRACT: Malta's domestic sector predominantly consume electric energy for the provision of comfort and operation of services within households. About 30% of the total national consumption is used by households, with the potable hot water production accounting for 24% of that energy. Nowadays, the major part of households heat water using an electric boiler, with an overall efficiency of 0.75. The EU Directive on Energy Efficiency 2012/27/EU and the Renewable Energy Directive 2009/28/EU, as well as the Energy Performance of Buildings Directive 2010/32/EC, have all identified energy use in buildings as the primary area where energy saving may have technically-sound and cost effective results. This paper focuses on the use of a thermodynamic heat pump for the production of potable hot water, which would reduce the electrical consumption in households. The Solar-Assisted Thermodynamic Heat Pump (SAHP) produces hot water using the primary energy source of solar energy and ambient air. Such a system is new to Malta and no local testing has been carried out to gauge its performance under local conditions. In this paper the potential application of a unitary type direct-expansion SAHP (DX-SAHP) system was examined. Testing was carried out during the most critical months between November and January.

Keywords: Solar-assisted Thermodynamic Heat Pump, Water Heating, Solar Energy, COP, Malta

1 INTRODUCTION

In its recent energy audit technical survey among 1,500 randomly selected households, the National Statistics Office has found that most Maltese families still depend on the traditional electric boiler to heat water for sanitary use [1]. Such boilers are used in 90.5% of households and consume almost 24% of the electricity bill.

On the other hand, solar water heaters can be used for space heating and hot water production, to reduce markedly the consumption of electricity in homes. In spite of the existence of capital grants on solar heaters since 2006, the uptake has been slow with an average of around 2,000 new solar heating installations every year [2].

It is also well known that over the past ten years, Malta's domestic buildings' stock has dramatically changed from single-family terraced houses to multi-storeys apartment blocks. This has reduced the effective un-shaded roof areas and has also reduced the percentage share of roof space available per household.

The overall effect of these changes seems to bear its toll on the popularity of solar water heaters, with 9.5% having a solar water heater [1], with occasional reporting of complaints on the non-existence of solar rights, which renders some systems inoperable, following the construction of extra storeys on existing buildings. Also, potential aesthetic problems when installing solar heaters, especially in scheduled areas or the village core, leaves the household with no option but to resort to gas heating (when possible and feasible) or continue to pay the current electricity bill, which is no longer as cheap as it was in the past.

Moreover, the most recent EU Directive on Energy Efficiency 2012/27/EU, which was published in December 2012, adds more pressure on energy end-use efficiency. It is imperative that the modus operandi of our energy consumption lifestyle has to change substantially, if one is to achieve any degree of energy end-use efficiency.

One of the easiest and most effective ways to address this deficiency in achieving lower energy consumption is by using heat pumps for water heating, instead of electric boilers. Previous research has shown that an air-to-water heat pump could reduce electricity consumption by almost 70%, when compared to an electric boiler [3]. Other research on energy performance of buildings has also shown that the use of heat pumps in households could reduce the electricity bill by up to 18% [4].

In practice, all of the above challenges together with all the potential benefits of heat pumps can be addressed by a solar-assisted thermodynamic heat pump, since due to its characteristic functions, the storage tank may be installed within the building, taking no more space than a washing machine, while its thermodynamic panel may be installed anywhere outside the building, on the roof or wall, in sunny, shaded or partially shaded areas, thus giving the SAHP an important versatility edge over a solar heater.

2 THE EU RE DIRECTIVE AND MALTA

According to the European Directive 2009/28/EC on the promotion of the use of energy from renewable sources [5], it is necessary to have a package of measures to reduce greenhouse gas emissions and comply with the Kyoto protocol [6] and with further community and international greenhouse emission reduction commitments beyond 2012. Also, it is aimed that such measures would control energy consumption and increase energy efficiency.

Heat pumps enabling the use of aero-thermal heat at a useful temperature level have been considered as contributing to renewable energy targets and goals, if their output significantly exceeds the primary energy needed to drive them. A specific formula has been set in the Directive to calculate this contribution, by taking into account the estimated total usable heat provided by heat pumps and the average seasonal performance factor for such heat pumps.

Malta's renewable energy (RE) target for 2020 has been set as 10%, with trajectory targets every 2 years starting from 2012. The trajectory RE targets are calculated as the average of the past 2 years, preceding the deadline date. For example, a 2% trajectory target by December 2012 implied an average RE contribution of 2% between January 2011 and December 2012. Clearly, Malta could not achieve this first trajectory, since the starting point in January 2011, the RE contribution was still very low. The forthcoming trajectory of 3% by 2014 is also a challenge, where the large diffusion of heat pumps for water heating could play an important role.

So far, Malta's National Renewable Energy Action Plan (NREAP) does not have any structured plans for the use of heat pumps for water heating, but primarily focus on wind energy, energy from waste and to some extent on photovoltaics [7]. This will probably have to change when Malta submits its revised NREAP in July 2013, not only to make good for the missed 2012 trajectory target, but also because heat pumps offer a quick, cost effective and easy to implement option for increasing the RE contribution.

3 STATE OF THE ART

In the past mainly two types of heat pump assisted solar systems were studied. These were Direct Expansion Solar-Assisted Heat Pumps (DX-SAHP) and Indirect-style Solar Assisted Heat Pumps (i-SAHP) [8].

In DX-SAHP systems, the solar thermodynamic panel is used as the evaporator in the cycle of the heat pump, where the refrigerant evaporates and absorbs energy, then passes to the electric compressor, and reaches the condenser, where it transfers the heat to the water storage, as shown in Figure 1. The refrigerant is then passes through an expansion valve, to reduce its temperature and thereby increase the energy absorption capacity when it returns to the thermodynamic panel.

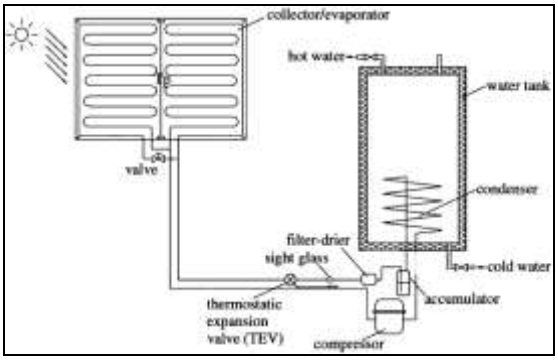

Figure 1: Direct Expansion Solar-assisted HP

For i-SAHP systems, one finds many possible system configurations. Unlike the DX-SAHP systems, the solar collector does not act as the evaporator for the heat pump, but the heat pump is installed in a closed circuit with a heat exchanger being the link between the thermodynamic panel and the heat pump, as shown in Figure 2 [9]. Such a configuration is useful where the distance between the thermodynamic panel and the heat pump is too long, thus saving on long refrigerant pipes.

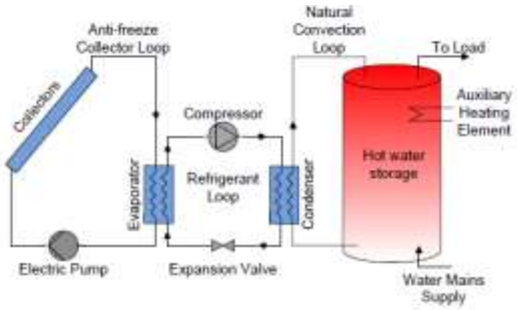

Figure 2: Indirect solar-assisted heat pump configuration (i-SAHP).

Some examples of i-SAHP systems which demonstrate the versatility and some of the many possible system configurations can also be found in Chandrashekar et al [10].

4 SYSTEM DESCRIPTION

This project involves the testing of a Direct Expansion Solar-assisted thermodynamic heat pump, which is a device that transfers thermal energy from a heat source to a tank of water. The heat pump used is the Spanish model Energy Panel Thermboil TBE 100, which is shown in Figures 3 and 4. The SAHP components are described in Table 1 [11].

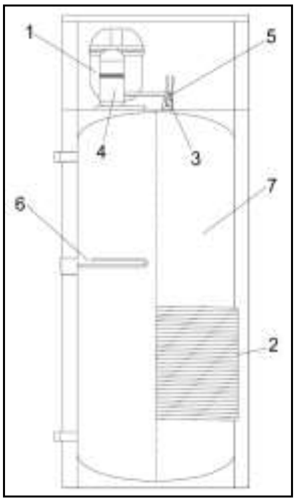

Figure 3. Components of DX-SAHP

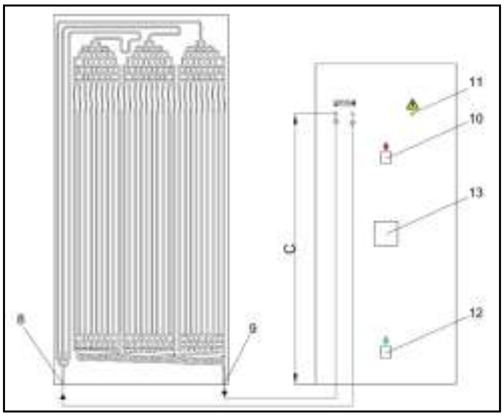

Figure 4. Thermodynamic panel connections

Table 1: Description of the components of DX-SAHP.

1	Compressor
2	Aluminum condenser
3	Drum
4	Dehydrator
5	Expansion valve
6	Electric back-up heater
7	Water tank
8	Liquid refrigerant inlet (impulsion)
9	Gas refrigerant outlet (aspiration)
10	Hot water outlet
11	Electrical connection
12	System water inlet
13	Electric back-up heater position

A thermodynamic panel works as the evaporator of the heat pump. For this study, the panel was installed facing south and at an angle of 45° to the horizontal, on top of the flat roof where testing is being conducted. Figure 5 shows the panel and its connection to the heat pump.

Figure 5. Photographs of the thermodynamic panel placed on the roof and the combined heat pump and storage tank, placed inside the room.

The refrigerant used is R134a, 1,1,1,2-Tetrafluoroethane, which is a haloalkane refrigerant with thermodynamic properties similar to R-12 (dichlorodifluoromethane), but with less ozone depletion potential. It has the formula CH_2FCF_3, and a boiling point of −26.3°C, at atmospheric pressure.

In order to calculate the efficiency of the system, it was deemed necessary to measure several variables: water inlet temperature, water outlet temperature and energy consumed by the compressor.

The measurement equipment used is detailed below:

• For measuring the water temperature and refrigerant temperature: Four PT-100 sensors together with an interface from PICO technology were connected to a dedicated laptop for data collection [12].

• Energy consumption together with other parameters pertaining to power, were measured using ELITE PRO recording polyphase power meter and a 50A hall sensor, from DENT Instruments [13]. This is an interval data recorder that can be used to measure and record a wide variety of physical parameters (voltage, current, active and reactive power, peak values, etc.).

5 RESULTS

5.1 COP Results

The first test procedure that was carried out on the SAHP, was to determine its COP when operating under standard hot water consumption for a family of 4 persons. Past research has determined that hot water consumption for showering in Malta averaged 30 litres per person per shower [14]. To that effect a standard daily hot water consumption of 120 litres was set for the SAHP, at the rate of 4 litres per minute.

Two modes of operation were chosen as follows:

- Hot water draw at 6:00 a.m. of 60 litres, followed by another one of 60 litres at 6:00 p.m. This mode of operation simulates one typical lifestyle with some family members taking showers in the morning, while others taking showers in the evening. This test would also yield the lowest expected COP of the heat pump, since the thermodynamic panel would only be absorbing energy from the air at relatively cold temperatures during the winter months.
- Full hot water draw of 120 litres at 12:00 noon. This test has been carried out to find the highest COP of the heat pump when operating during the day when the ambient temperature is higher and also when the sun is shining. In this case, the thermodynamic panel would absorb energy both from the air and from the sun.

Also, at the beginning of the test period, a number of extra tests were carried out to simulate particular cases such as mid-day and mid-night hot water use, as well as more frequent drawing of water every 6 hours.

After measuring and evaluating the input and output variables listed above, the COP of the SAHP was calculated for each experiment, during the months of November 2012 to January 2013, as shown in Table 2.

Table 2: Average COP results for different test.

DATE	TEST MODE	avg COP
3-7 Nov. 2012	120 litres at 16.00h	3.84
17-26 Nov. 2012	60L at 0.00h, 60L at 12.00h	3.73
10-16 Dec. 2012	60L at 0.00h, 60L at 12.00h	4.98
21-27 Dec. 2012	60L at 0.30h, 60L at 6.30h,60L at 12.30h, 60L at 18.30h	3.44
3-9 Jan. 2013	120 litres at 12.00h	3.91
10-17 Jan. 2013	60L at 6.00h, 60L at 18.00h	3.21
21-27 Jan. 2013	120litres at 12.00h	4.71

The COP was calculated as shown below:

$$COP = \frac{Q_{heat}(kWh)}{E_{Elec}(kWh)}$$

where :

- Q_{heat} is the energy output in kWh needed to change the temperature from inlet to outlet temperature within the storage tank of the heat pump.
- E_{elec} is the total electrical energy input in kWh, which is the product of time, current, voltage and power factor.

The results show that the COP is quite high for all tests. Moreover, the COP increases even more when the heat pump operates during noon time (i.e. at the peak of sunshine) by another 30% over the COP of the heat pump when operating without sunshine. This is an added bonus that is not available for other types of air-to-water heat pumps that have no thermodynamic panel.

Tables 3 and 4 show more detailed results for the periods 17 to 26 November and 21 to 27 December 2012, respectively. The marked difference in Table 3, between heat pump operation at 12 noon and at midnight is clear and systematic for all days of the test. It is to be noted that the solar irradiation is the cumulative energy falling on the thermodynamic panel during the operation of the heat pump only.

Table 3: Daily COP results, together with the ambient temperature, solar irradiation, water inlet temperature and hot water temperature, during the operation of the heat pump, for November 2012.

DATE	Hour	COP	T_{amb} (°C)	Solar irr. (kWh/m^2)	T_{in} (°C)	T_{out} (°C)
17 Nov	12.00	5.10	19.24	0.37	21.60	55.69
18 Nov	0.00	3.19	16.12	0.00	18.59	53.84
18 Nov	12.00	4.24	20.33	1.19	20.69	54.02
19 Nov	0.00	3.38	15.02	0.00	18.14	53.13
19 Nov	12.00	4.05	19.71	0.74	20.25	54.12
20 Nov	0.00	3.18	15.47	0.00	17.53	53.27
20 Nov	12.00	3.99	18.07	0.96	19.45	53.70
21 Nov	0.00	3.27	15.14	0.00	17.88	53.30
21 Nov	12.00	3.99	19.05	0.97	20.28	54.03
22 Nov	0.00	3.23	15.44	0.00	18.19	53.62
22 Nov	12.00	4.21	19.10	0.50	20.48	53.83
23 Nov	0.00	3.04	15.81	0.00	17.75	53.17
23 Nov	12.00	3.93	19.60	1.14	20.16	53.68
24 Nov	0.00	3.09	14.67	0.00	18.11	53.51
24 Nov	12.00	3.78	19.64	0.56	19.70	53.84
25 Nov	0.00	3.06	15.10	0.00	17.31	53.55
25 Nov	12.00	4.46	19.09	0.60	19.86	54.24
26 Nov	0.00	3.19	14.31	0.00	16.70	53.64
26 Nov	12.00	4.46	19.69	1.43	19.98	53.71

Table 4: Daily COP results, together with the ambient temperature, solar irradiation, water inlet temperature and hot water temperature, during the operation of the heat pump in December 2012.

Date	Hour	COP	T_{amb} (ºC)	Solar Irr. (kWh/m^2)	T_{red} (ºC)	T_{out} (ºC)
21 Dec	0.30	3.34	11.29	0.00	13.84	53.72
21 Dec	6.30	4.10	10.34	0.47	14.08	53.57
21 Dec	12.30	4.13	14.50	1.67	16.68	53.29
21 Dec	18.30	3.38	11.27	0.00	16.77	53.21
22 Dec	0.30	3.24	10.09	0.00	15.94	52.99
22 Dec	6.30	3.21	14.42	0.02	15.57	52.94
22 Dec	12.30	3.83	16.40	0.73	16.40	53.19
22 Dec	18.30	3.36	14.65	0.00	15.76	53.14
23 Dec	0.30	3.16	14.59	0.00	14.70	52.95
23 Dec	6.30	3.37	12.58	0.04	14.27	53.01
23 Dec	12.30	4.39	14.05	0.96	16.43	53.72
23 Dec	18.30	3.17	12.58	0.00	16.00	52.74
24 Dec	0.30	3.03	12.74	0.00	14.75	52.83
24 Dec	6.30	3.45	11.64	0.43	14.78	53.11
24 Dec	12.30	3.66	15.60	1.83	16.97	53.42
24 Dec	18.30	3.17	12.85	0.00	17.09	53.18
25 Dec	0.30	2.78	11.83	0.00	15.45	52.73
25 Dec	6.30	3.40	13.59	0.44	14.43	53.06
25 Dec	12.30	4.16	15.60	0.45	17.50	53.56
25 Dec	18.30	3.42	14.60	0.00	17.18	53.16
26 Dec	0.30	3.36	11.32	0.00	16.35	52.66
26 Dec	6.30	3.36	11.81	0.39	16.21	52.44
26 Dec	12.30	3.66	17.61	1.68	18.07	52.87
26 Dec	18.30	3.07	15.74	0.00	17.31	52.77
27 Dec	0.30	3.00	15.80	0.00	15.86	52.64
27 Dec	6.30	3.23	16.14	0.36	15.48	52.62

Figure 6 shows a plot of the results obtained for the dates 3-9 January 2013. It is seen that the COP actually increases when the heat pump operates during significant sunshine hours. While in Figure 7, it is seen that the COP drops as the ambient temperature drops, in the absence of solar radiation. The same results have been obtained for the previous months of November and December.

5.2 Contribution of the SAHP to Renewable Energy

In accordance with the EU Renewable Energy Directive 2009/28/EC, it is possible to calculate the RE contribution of this heat pump. It is necessary to obtain the seasonal performance factor (SPF), which should be the average for a whole year of operation.

From the results obtained so far and knowing that this time of the year would be yielding the lowest performance factors, the minimum SPF that one would expect is 3.91. This value exceeds the minimum value specified by the RE Directive to make this heat pump eligible for consideration.

The SPF was calculated, according to the Renewable Energy Directive as the ratio between the power used by the SAHP for hot water production and electric energy consumed by the pump, including water re-heating periods. The SPF values obtained for the different weeks studied are shown in Table 5.

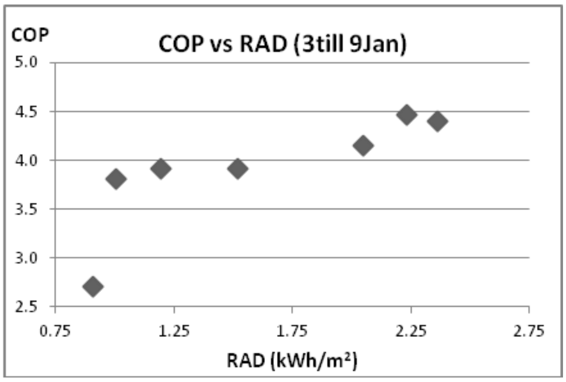

Figure 6. The COP versus solar radiation during mid-day tests.

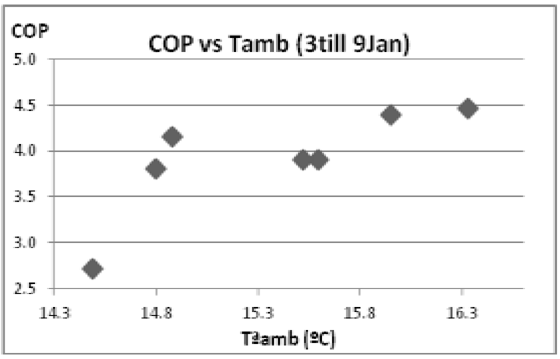

Figure 7. Representation COP vs radiation.

Table 5: Average SPF results for different test.

DATE	TEST MODE	avg SPF
3-7 Nov. 2012	120 litres at 16.00h	3.84
17-26 Nov. 2012	60L at 0.00h, 60L at 12.00h	3.73
10-16 Dec. 2012	60L at 0.00h, 60L at 12.00h	4.98
21-27 Dec. 2012	60L at 0.30h, 60L at 6.30h,60L at 12.30h, 60L at 18.30h	3.44
3-9 Jan. 2013	120 litres at 12.00h	3.91
10-17 Jan. 2013	60L at 6.00h, 60L at 18.00h	3.21
21-27 Jan. 2013	120litres at 12.00h	4.71

According to the Directive, the amount of aerothermal energy captured by a heat pump to be considered as energy from renewable sources (E_{RES}) shall be calculated in accordance with the following formula:

$$E_{RES} = Q_{USABLE} \cdot \left(1 - \frac{1}{SPF}\right)$$

Where:

- Q_{USABLE} is the estimated total usable heat delivered by the heat pump.

It is important to understand that hot water will not be needed at the same volume for the whole year. For the purpose of this study, the percentage use was assumed to be 25% for summer, 75% for spring and autumn and 100% for winter. The winter hot water consumption representing 100% of the demand has been determined in this study.

Hence, the amount of renewable energy contribution of each heat pump may be calculated as 1,238.47 kWh/year, with the SPF taken as that found in this study. In reality, the SPF would be higher for spring, summer and autumn and hence the results reported here are conservative.

Assuming that total number of Maltese households are 130,000, and considering that 50% of them are apartments and hence may not be able to install a solar heater, the total renewable energy produced from heat pumps for Malta could reach 80,500 GWh/year, equivalent to 6.92 ktoe. This would represent 1.30% of the total final energy consumed in Malta by 2020 [15].

5.3 Heat Loss in Stand-by Conditions

Unavoidably, some heat losses are to be expected from the hot water storage tank to the indoor surrounding, in spite of the good insulation of the tank. The energy lost in stand-by mode may be calculated as follows:

$$Q = v \cdot \rho \cdot C_p \cdot \Delta T$$

where:

v: volume of water= 0.1 m^3

ρ: density of water= 1000 kg/m^3

C_p: specific heat capacity of water = 4.18 kJ/kgK

ΔT: Temperature drop between compressor switching off and on.

The heat losses for the different months that have been studied are shown in Table 6 below. The mean energy loss in stand-by mode per day was very similar for the 3 months, because the storage tank hot water is located inside the building, so that the outside temperature variations on the tank are minimal. However, it is interesting to note that the average re-heating COP is very low. This is due to the fact that the water in the tank is already high (around 50 °C) and the compressor is only operating to raise that temperature to the set temperature of 55 °C. It is more difficult to pump heat into a hot reservoir and hence the COP drops. Solutions to avoid operating the heat pump at such a low COP could be either to install a timer that will block the operation of the heat pump at certain times, to avoid cyclic re-heating or otherwise, increase the differential temperature at which the compressor kicks in to re-heat.

Table 6: Energy losses

Date	Test Mode	Energy losses (kWh/day)	Re-heating COP
17-26 Nov.2012	60L at 0.00h, 60L at 12.00h	0.31	1.88
10-16 Dec.2012	60L at 0.00h, 60L at 12.00h	0.44	1.33
10-17 Jan.2013	60L at 6.00h, 60L at 18.00h	0.36	1.59
	Average	**0.37**	**1.60**

Compared to the actual average energy drawn from the tank in terms of hot water, the heat losses form around 8%. However, it is still considered important to reduce losses as much as possible. If one were to install a timer that costs around €10, and given that the current cost of electricity is €0.17 per kWh, it can be easily realized that the cost of the timer may be recovered in less than one year. At the same time, one would have saved the energy consumed in operating the heat pump which would amount to around 84 kWh/annum.

6 ANALYSIS OF RESULTS

Results have shown that the COP achieved is high for all experiments. The average COP of 3.97 is much higher than an electric boiler, which normally operates at 0.75, as was shown in previous research [3]. Effectively, this implies that a heat pump of this type would save 4 times the electrical energy consumed in a typical electric boiler. Moreover, this type of heat pump has the potential of achieving even higher COP, if it is made to operate during sunshine hours rather than early morning and later evenings. This is practically possible by introducing a timer.

Comparing the tests performed at noon time, the highest COP is obtained during the warmer month of November and when the sun is shinning, since the thermodynamic panel would absorb energy from the sun as well as the air. Hence, it is expected that the COP of this machine would be much higher in spring, summer and autumn than when it is in winter.

7 CONCLUSIONS

Comparing the SAHP with traditional electric boilers, it is clear that the heat pump offers superior performance, both in terms of electrical consumption and carbon dioxide reduction. It is however noted that the performance of the heat pump is dependant on external factors such as the inlet cold water temperature, the ambient air temperature and the availability of solar radiation.

It has been confirmed that the SAHP operates very well in the climate of Malta, even in rainy or cloudy days, given that the ambient temperature hardly drops below 5°C.

Although the SAHP can work in shady areas, it would operate more efficiently when the thermodynamic panel is exposed to the sun, but not necessarily on the roof or at a specific inclination.

For the same reason, it is preferable that the heat pump is made to operate during daylight rather than at night, both due to the availability of solar radiation and the fact that the air temperature would be higher during the day.

The SAHP under test could potentially produce a renewable energy contribution of 1238.47 kWh/year, when used by a family of 4 under the set conditions of this study (100% in winter, 75% in spring and autumn, 25% in summer).

It is necessary to highlight the ease of installation of this equipment, as it only needs an electrical outlet, and refrigerant connections to the thermodynamic panel.

It is known that solar heating systems, along with current fiscal support schemes for the domestic sector in Malta today, are the first choice for water heating in Malta. But for cases where, due to lack of space or roof or other practical reasons, the SAHP should also be supported in fiscal terms pro-rata, since it also contributes towards the achievement of Malta's renewable energy target. This may also contribute towards increasing social justice, since not all households have roofs for installing solar heaters.

8 REFERENCES

[1] George Said, National Statistics Office, Development of Detailed Statistics on Energy Consumption in Households Final Report, Grant Agreement No. 30304.2009.003-2009.704, Malta.

[2] Malta Resources Authority, private communication.

[3] S. Morentin Gutiérrez, C. Yousif and R.N. Farrugia, Testing of an Air Source Heat Pump Water Heater in Malta, Proceedings of the World Renewable Energy Congress XI, Abu Dhabi, United Arab Emirates, 25-30 September 2010, Future Technology Press, pp. 508-513.

[4] Charles Yousif, Celia Perez Garcia and Francisco Javier Rey Martínez, Energy Performance of Residential Buildings in Malta, The 3rd International Conference on Passive and Low Energy Cooling for the Built Environment (PALENC 2010), 5th European Conference on Energy Performance & Indoor Climate in Buildings (EPIC 2010) and 1st Cool Roofs Conference, Rhodes, Greece, 29 Sep – 1 Oct, 2010.

[5] Directive 2009/28/EC of European parliament and of the council of 23th April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing directives 2001/77/EC and 2003/30/EC.

[6] Kyoto Protocol to the United Nations Framework Convention on Climate Change. United Nations, 1998.

[7] Malta Resources Authority, Photovoltaics in New Member States Project (PVNMS-NET) Workshop, Malta, 18 February 2011.

[8] S.J. Sterling , M.R. Collins, Feasibility analysis of an indirect heat pump assisted solar domestic hot water system, Applied Energy 93 (2012) 11–17, Elsevier, ScienceDirect, 2012.

[9] Bridgeman A, Harrison SJ. Preliminary experimental evaluations of indirect solar assisted heat pump systems. In: 3rd Canadian solar building conference, August 20–22, Fredericton, New Brunswick, Canada; 2008.

[10] Chandrashekar M, Le NT, Sullivan HF, Hollands KGT. A comparative study of solar assisted heat pump systems for Canadian locations. Sol Energy 1982; 28(3):217–26.

[11] Energy Panel SL, User Manual Thermboil TB E, Lucena, Córdoba, Spain (www.energypanel.es).

[12] Pico Technology, http://www.picotech.com/pt100.html

[13] Dent Instruments, http://www.dentinstruments.com

[14] C. Yousif, C. Fernandez Vazquez and V. Buhagiar, Performance Analysis of Water-in-Glass Evacuated-Tube Solar Heating Systems in Malta, Proceedings of the 1st International Congress on Heating, Cooling and Buildings, EUROSUN2008, 7-10 October 2008, Lisbon, Portugal, Ref. No. 028.

[15] Energy Transparency Platform http://ec.europa.eu/energy/renewables/action_plan_en.htm